SELF-OPTIMIZING CLASSIFIER

Background of the Invention

Technical Field

The invention relates to a method and computer

5   program product for producing an optimal classifier model

for a pattern recognition system. Image processing

systems often contain pattern recognition systems.

Description of the Prior Art

Pattern recognition systems, loosely defined, are

10 systems capable of distinguishing between various classes

of real world stimuli according to their divergent

characteristics. A number of applications require pattern

recognition systems, which allow a system to deal with

unrefined data without significant human intervention. By

way of example, a pattern recognition system may attempt

to classify individual letters to reduce a handwritten

document to electronic text. Alternatively, the system

may classify spoken utterances to allow verbal commands to

5   be received at a computer console.

A typical prior art classifier is trained over a

plurality of output classes using a set of training

samples. The training samples are processed, data

relating to features of interest are extracted, and

10   training parameters are derived from this feature data.

As the system receives an input associated with one of a

plurality of classes, it analyzes its relationship to each

class via a classification technique based upon these

training parameters. From this analysis, the system

15   produces an output class and an associated confidence

value.

Designing a pattern recognition classifier for a

specific application is generally a hit or miss task. It

often requires multiple iterations and a significant

20   amount of time to develop a working system. Further, in

some applications, new output classes frequently appear in

the population of samples classified by the system. For

these applications, it is necessary to regularly add new

output classes to reflect changes in the data population.

Without some method of identifying new classes, the system will not be able to deal with the novel patterns effectively. Once discovered, it will also be necessary to retrain the classifier to accept the new class. To

5 maintain optimal system performance, it may be necessary to reconfigure the design of the classifier in light of the newly added output classes, requiring another lengthy training process.

10 **Summary of the Invention**

To this end, according to one aspect of the invention, a method is presented for determining an optimal classifier model for a pattern recognition system. An initial plurality of classifier models are selected

15 from a set of generated classifier models. An optimal representative classifier model is generated according to an iterative optimization routine. The representative classifier having the highest associated value for a fitness function is accepted.

20 In one embodiment of the invention, the iterative process can include a series of steps that are repeated until the occurrence of a termination event. For example, the termination event can be the satisfaction of a fitness function threshold. Within the iterative process of the

example embodiment, any combination of one or more of the following steps may comprise a portion of the iterative loop of the process. An architecture can be determined for each selected classifier model according to an

5 optimization algorithm. At least one numerical parameter can be optimized within a determined architecture. A set of optimum features can be determined for a determined architecture.

In accordance with another aspect of the invention, a

10 method is described for automatically updating a pattern recognition classifier to recognize additional classes. A plurality of rejected pattern samples are grouped into clusters according to similarities among the pattern samples. At least one database is searched to identify at

15 least one of the clusters of rejected pattern samples. If one or more clusters are not identified in the database search, at least one cluster not identified in the database search is submitted to an expert verifier for identification. The pattern samples from the identified

20 clusters are then added to a set of training samples.

In accordance with yet another aspect of the invention, a computer program product is disclosed for determining an optimal classifier model for a pattern recognition system. A system control program selects a

plurality of classifier models from a set of generated

classifier models. An iterative loop produces an optimal

representative classifier for each classifier model,

according to an iterative optimization routine. The

5   system control program accepts the representative

classifier having a best associated value for a fitness

function at the termination of the optimization routine.

In one embodiment of the computer program product,

the iterative loop can comprise one or more of the

10   following subroutines. The architecture determination

portion can determine an architecture for each selected

classifier model according to an optimization algorithm.

A parameter optimizer can optimize at least one parameter

within a determined architecture. A feature optimizer can

15   select an optimal set of features for a determined

architecture.

In accordance with another aspect of the invention, a

computer program product is disclosed for updating a

pattern recognition classifier to recognize new classes.

20   A clustering portion groups a plurality of rejected

pattern samples into clusters according to the

similarities between the pattern samples. An artificially

intelligent trained program searches at least one database

to identify at least one of the clusters of rejected

pattern samples.   If one or more clusters are not

identified in the database search, a controller program

submits at least one cluster not identified in the

database search to an expert verifier for identification.

5   The controller program adds the pattern samples from the

identified clusters to a set of training samples.

Brief Description of the Drawings

The foregoing and other features of the present

10   invention will become apparent to one skilled in the art

to which the present invention relates upon consideration

of the following description of the invention with

reference to the accompanying drawings, wherein:

Fig. 1 is an illustration of an exemplary neural

15   network utilized for pattern recognition;

Fig. 2 is a flow diagram illustrating the operation

of training portion of the self-optimizing classifier of

the present invention;

Fig. 3 is a flow diagram illustrating the run-time

20   operation of the self-optimizing classifier;

Fig. 4 is a functional block diagram of an example

embodiment of the training portion of the self-optimizing

classifier; and

Fig. 5 is a functional block diagram of an example embodiment of the learning portion of the self-optimizing classifier.

5 **Detailed Description of the Invention**

In accordance with the present invention, a self-optimizing pattern recognition classification system that optimizes to a specific set of training samples is described. The classifier can be used in any traditional

10 pattern recognition classifier task, including, for example, optical character recognition (OCR), speech translation, and image analysis in medical, military, and industrial applications.

It should be noted that the present invention, as one

15 embodiment, can be implemented as a computer program. Therefore, the structures described herein can be considered to refer to individual modules and tasks within these programs. Portions of the present invention are intended to emulate the function of a neural network.

20 Accordingly, understanding of the present invention will be facilitated by an understanding of the operation and structure of a neural network.

Fig. 1 illustrates a neural network that might be used in a pattern recognition task. The illustrated

neural network is a three-layer back-propagation neural
network used in a pattern classification system. It
should be noted here, that the neural network illustrated
in Fig. 1 is a simple example solely for the purposes of
illustration. Any non-trivial application involving a
neural network, including pattern classification, would
require a network with many more nodes in each layer. In
addition, further hidden layers might be required.

In the illustrated example, an input layer comprises
five input nodes, 1-5. A node, generally speaking, is a
processing unit of a neural network. A node can receive
multiple inputs from previous layers which it processes
according to an internal formula. The output of this
processing can be provided to multiple other nodes in
subsequent layers. The functioning of nodes within a
neural network is designed to mimic the function of
neurons within a human brain.

Each of the five input nodes 1-5 receives input
signals with values relating to features of an input
pattern. The term "features" is here intended to
encompass any quantifiable data useful for distinguishing
among output classes that can be extracted from the
pattern, including a bit by bit input of the pattern
itself in either an original or a compressed form. By way

of example, the signal values could relate to the portion

of an image within a particular range of grayscale

brightness. Alternatively, the signal values could relate

to the average frequency of an audio signal over a

5   particular segment of a recording. Preferably, a large

number of input nodes will be used, receiving signal

values derived from a variety of pattern features.

Each input node sends a signal to each of three

intermediate nodes 6-8 in the hidden layer. The value

10   represented by each signal will be based upon the value of

the signal received at the input node. It will be

appreciated, of course, that in practice, a classification

neural network can have a number of hidden layers,

depending on the nature of the classification task.

15   Each connection between nodes of different layers is

characterized by an individual weight. These weights are

established during the training of the neural network.

The value of the signal provided to the hidden layer by

the input nodes is derived by multiplying the value of the

20   original input signal at the input node by the weight of

the connection between the input node and the intermediate

node. Thus, each intermediate node receives a signal from

each of the input nodes, but due to the individualized

weight of each connection, each intermediate node receives

a signal of different value from each input node. For

example, assume that the input signal at node 1 is of a

value of 5 and the weight of the connection between node 1

and nodes 6-8 are 0.6, 0.2, and 0.4 respectively. The

5   signals passed from node 1 to the intermediate nodes 6-8

will have values of 3, 1, and 2.

Each intermediate node 6-8 sums the weighted input

signals it receives. This input sum can include a

constant bias input at each node. The sum of the inputs

10   is provided into a transfer function within the node to

compute an output. A number of transfer functions can be

used within a neural network of this type. By way of

example, a threshold function can be used, where the node

outputs a constant value when the summed inputs exceed a

15   predetermined threshold. Alternatively, a linear, sigmoid

or other appropriate function can be used, passing the

value of the function evaluated at the input sum to the

nodes of the next layer.

Regardless of the transfer function used, the

20   intermediate nodes 6-8 pass a signal with the computed

output value to each of the nodes 9-13 of the output

layer. An individual intermediate node (i.e. 7) will send

the same output signal to each of the output nodes 9-13,

but like the input values described above, the output

signal value will be weighted differently at each individual connection. The weighted output signals from the intermediate nodes are summed to produce an output signal. Again, this sum can include a constant bias

5 input.

Each output node represents an output class of the classifier. The value of the output signal produced at each output node represents the probability that a given input sample belongs to the associated class. In the

10 example system, the class with the highest associated probability is selected, so long as the probability exceeds a predetermined threshold value. The value represented by the output signal is retained as a confidence value of the classification.

15 Turning to the present invention, the self-organizing classifier can be considered as two parts, a training portion and a learning portion. The training portion creates and optimizes the classifier model through an optimization process. The learning portion represents the

20 run-time operation of the classifier. The learning portion collects samples that the classifier model could not identify with a sufficiently high level of confidence and obtains class information for these samples. When samples representing new classes are discovered, these

samples are added to the training set, and the classifier
is retrained and optimized on the new samples.

Fig. 2 illustrates the operation of training portion
of the self-optimizing classifier of the present

5   invention. The process 20 begins at step 22. It then
proceeds to step 24, where regions of interest, portions
of a pattern that can contain recognizable data, are
segmented from a plurality of pattern samples. These
segmented regions of interest are referred to as candidate

10 objects, and the segmentation of images into candidate
objects is known in the art. The process then advances to
step 26, where feature data is extracted from the
candidate objects. Feature extraction converts the
pattern into a vector of numerical measurements, referred

15 to as feature variables. Thus, the feature vector
represents the input data in a compact form. Many feature
types exist and are selected based on the characteristics
of the recognition problem.

After the feature vectors are extracted from the

20 candidate objects, the process continues to step 28. At
step 28, the extracted feature vectors are clustered to
determine appropriate output classes. In an example
embodiment, the pattern segments are input into a self-
organizing map to determine a natural clustering of the

training vectors. A class designation for the clustered

pattern segments is assigned according to the cluster in

which the segment is located. In an alternate embodiment,

the output classes and the associated class of each of the

5   clustered segments can be predetermined by a human

operator.

The process then advances to step 30. At step 30, a

set of minimum features is defined for the classification

analysis. The minimum feature set includes those features

10   necessary to define an n-dimensional feature space in

which all of the output classes are distinct and well

separated. The extracted feature data is subjected to a

factorial or component analysis to determine the

contribution of each factor to providing separation

15   between the defined output classes. This can include

various types of factorial analysis of variance, principle

component analysis, and similar statistical techniques.

The process then proceeds to step 32, where a

plurality of classifier models are selected. These

20   classifier models can be preselected by an operator or

selected by the system according to rule-based logic

encoded in a configuration file. The term classifier

model is intended to refer to the abstract framework of a

classifier system, as opposed to the internal architecture

or specific parameters of the classifier. The classifier models can include both neural network models such as the back propagation neural network, one of its variants (e.g., QuickProp), auto-associative networks, self-

5   organizing maps, or various radial basis function networks, as well as non-neural network models, such as boosting and bagging classifiers and support vector machines.

For each classifier model selected, an iterative

10   optimization process takes place to produce an optimal classifier for the given training set. The optimization process can be performed in parallel or in series for the selected classifier models, depending on the system resources available.

15   The optimization process begins at step 34, where one of the selected classifier models is provided to the optimization loop. At step 36, the internal architecture of a classifier based on the provided model is altered according to an optimization algorithm. At this step, the

20   internal structure and mechanics of the network can be changed in an attempt to produce a more efficient classifier system. For example, in a neural network classifier, these changes can include adding or removing nodes, layers, or interlayer connections. In a self-

organizing map, the number of map units can be changed as well as the radius of the learning neighborhood.

The process proceeds to step 38, where the classifier represented by the determined architecture is initialized.

5 Through initialization, the classifier is set to an initial state to facilitate later training and optimization. In a neural network classifier, for example, the weights of the classifier are set to an initial value, usually a random value.

10 At step 40, the internal parameters of the classifier represented by the determined architecture are optimized. At this step, the necessary internal parameters, such as weights, kernels, or statistical class parameters, are calculated as to maximize the ability of the classifier to

15 distinguish between the output classes. This can be done via a number of methods, including genetic algorithms, gradient-based searching, and simulated annealing techniques. A cost function based on the complexity and accuracy of the system can be used as a metric for this

20 optimization. The technique used for optimization will depend strongly on the classifier model used. For example, some classifier models, such as back-propagation neural networks, implicitly include an optimization method. These models can be used in combination with a

second optimization method to improve the accuracy and efficiency of classification.

After the classifier parameters are optimized, the process proceeds to step 42, where an optimal feature set

5   for the classifier represented by the determined architecture is selected. An optimization algorithm is used to select the features that minimize a cost function, based on the processing time necessary to implement the feature and the accuracy obtained with the feature.

10 Useful optimization techniques include genetic algorithms, discrete gradient searches, and similar techniques.

After the features are selected, the process continues to step 44, where the performance of the classifier architecture is evaluated. In evaluating the

15 architecture, a test set of pattern samples with known class associations is submitted to the classifier. The classification results are compared to the known associations to determine the accuracy of the classifier represented by the architecture. A fitness function is

20 calculated based upon the complexity of the system and the accuracy and completeness of the classifier's classification of the test set. The fitness function will vary depending on the classifier model selected and the intended application of the classifier.

The system then proceeds to step 46. At step 46, the internal architecture, optimal parameters, and optimal features are saved to memory along with the results of the evaluation. To preserve memory, only architectures

5   meeting certain fitness criteria can be saved in the memory. For example, the memory may store only a predetermined number of the fittest architectures, requiring a newly generated architecture to surpass the fitness of the existing architectures to be stored in

10 memory.

The process then proceeds to step 48, where the system checks for a termination event. Examples include the fitness function meeting a threshold value, an elapsed period of time, or an elapsed number of iterations. If no

15 termination event has occurred, the process returns to step 34 to generate new classification structures for comparison. If a termination event has occurred, the classifier represented by the architecture with the best fitness value is retained as a representative classifier

20 at step 50.

At step 52, the system determines if any of the selected classifier models remain to be optimized. If so, the process returns to step 34, where one of the remaining classifier models is provided for optimization. After all

of the classifier models have been optimized, the process

advances to step 54, where the representative classifier

for each model is evaluated according to a second fitness

function. This fitness function will be a function of the

5   complexity of the classifier and the accuracy and

completeness of its classification of the test set at step

44. The specifics of the fitness function will vary with

the application. Once the fitness of each classifier has

been calculated, the classifier producing the best fitness

10   value is selected. The process then terminates at step

56.

Fig. 3 illustrates the run-time operation of the

self-optimizing classifier of the present invention. The

process 60 begins at step 62 and proceeds to step 64,

15   where an input pattern is acquired and preprocessed.

During preprocessing, the pattern is enhanced, portions of

interest are located, and obvious noise is eliminated.

The process then proceeds to step 66, where feature data

is extracted from the pattern in the form of feature

20   vectors. The feature extraction process of the learning

portion is similar to that described above and will not be

described further here.

The process then advances to step 68, where the

system determines if the input pattern is associated with

an output class represented by the system. The specifics

of this determination will vary depending on the

classifier produced during the training stage. If the

system determines that the input pattern is associated

5   with a represented output class, the process proceeds to

step 70, where the system outputs the classification

result and returns to step 64 to process another input

pattern.

If the input pattern is rejected (i.e. not determined

10   to be associated with a particular class), the process

advances to step 72, where the pattern is stored in

memory. The process then advances to step 74, where the

system determines if a sufficient number of samples have

been collected to conduct a clustering analysis. If an

15   insufficient number of samples have been collected, the

system returns to step 64 to process another pattern.

If a sufficient number of pattern samples have been

collected, the learning process begins. At step 76, the

collected patterns are grouped into clusters according to

20   their proximity in feature space. In other words,

patterns possessing similar features are grouped together,

according to a clustering algorithm. A number of

clustering algorithms exist for use in this application,

including k-means algorithms, gradient search techniques, and self-organizing maps.

The process then advances to step 78, where the system determines if any of the clusters could represent a

5   new class. The criteria for this determination will vary, but it will generally focus on the density of the cluster. If a large number of pattern samples are gathered within a relatively small cluster, the cluster likely represents a class. The exact density necessary to represent a class

10   will be determined by experimentation with a particular application. If no sufficiently dense cluster is found, the learning process terminates, and the classifier continues its run-time operation at step 64.

If any clusters are sufficiently dense to represent a

15   new class, the process proceeds to step 80, where the clusters are checked against a database containing information about possible output classes by an artificially intelligent trained search program, or BOT. This can be accomplished by a number of methods including

20   classification techniques, distance comparisons, or clustering algorithms. It should be noted that the database of possible classes need not be a single database. The BOT is capable of obtaining data even from unprepared sources, such as preselected Internet web pages

pertaining to the subject of interest. Appropriate

samples can be identified via a rough classifier that

detects patterns of an appropriate type or through

heuristic rules that identify samples that are likely to

5   be of interest for a particular application.

For example, for a face recognition application, the

BOT could search the FBI website to determine if the

unmatched face belongs to a wanted criminal. In an

alternate embodiment, the BOT could also conduct a general

10 Internet search to locate possible samples. Generally,

due to verification issues with online content, an

Internet search would be useful mainly for finding an

official or pre-verified site that has changed its Uniform

Resource Identifier (URI). These sites can be verified by

15 the similarity of content between the original page and

the retrieved page. Where a specific resource is sought,

however, it is possible to conduct a general Internet

search on preselected application specific terms to find

samples fitting a narrow range of characteristics. In

20 such a case, either a verification routine or an expert

verifier will be necessary to ensure that the retrieved

samples are valid.

At step 82, it is determined if any class samples

within the databases match the calculated cluster mean

vectors. If class information is found in the databases, the process proceeds to step 84, where the cluster is identified as belonging to the located class and the pattern samples therein are added to a set of training

5   vectors. The results are reported at step 86 and the learning process is terminated at step 88. The system then returns to the training process, where the classifier can be retrained on the newly classified samples.

If the cluster does not match a known class, the

10   process advances to step 90, where the clusters are subjected to an expert verifier to identify new pattern classes. The expert verifier can take a number of forms. In one embodiment, the clustered pattern data is outputted to a human operator for review. Alternatively, the

15   clustering can be verified by a computerized process, such as a modified clustering algorithm or a specialized classifier.

The process then proceeds to step 92, where the expert verifier determines if the cluster represents a new

20   output class for the classifier. If not, the process advances to step 86 where the results are reported and then terminates at step 88. If so, the process continues at step 94, where the new class is identified by the expert verifier, and its information is added to the

database. The process then continues to step 86 where the
result is reported, and the learning process terminates at
step 88. The system then reverts to the training stage to
train the classifier to recognize the new class.

5   Fig. 4 is a functional diagram of an example
embodiment of the training portion of the self-optimizing
classifier of the present invention implemented as
computer software within a data processing system. In the
example embodiment, the input patterns are images of
10 envelopes and the objects to be classified are postal
indicia.

The training portion 100 includes a memory 102
containing a plurality of envelope image samples. A
region of interest extractor 104 segments detected postal
15 indicia within the envelope images. At this stage,
portions of the envelope image that may contain a stamp or
other significant marking are removed from the image and
saved as separate images. Such image segmentation is well
known in the art.

20   The segmented images are then passed to a feature
extractor 106. The feature extractor 106 analyzes
preselected features of the pattern. The selected
features can be literally any values derived from the
pattern that vary sufficiently among the various output

classes to serve as a basis for discriminating among them.
Numerical data extracted from the features can be
conceived for computational purposes as a feature vector,
with each element of the vector representing a variable

5   value for one feature within the pattern. A large number
of feature variables will be available; many divided into
groups of related features known as feature groups. In
the example embodiment, two examples of feature variable
groups include a histogram feature variable group, and a

10   compressed image feature variable group.

A scanned grayscale image consists of a number of
individual pixels, each possessing an individual level of
brightness, or grayscale value. The histogram feature
variables focus on the grayscale value of the individual

15   pixels within the image. Each of the histogram feature
variables represents a range of grayscale values. The
values for the histogram feature variables are derived
from a count of the number of pixels within the image
having a grayscale value within each range. By way of

20   example, the first histogram feature variable might
represent the number of pixels falling within the lightest
sixteenth of the range of all possible grayscale values.

The compressed image variables represent the average
grayscale values of the pixels within a number of

preselected areas of the image. By way of example, these areas can be defined by a number of equally spaced grids superimposed across the image. Thus, the first variable could represent the average or summed value of the pixels

5 within the upper left region of the grid.

The extracted feature variables are input into a classifier initializer 108. The classifier initializer clusters the inputted feature vectors to determine both the output classes of the system and the class associated

10 with each of the input patterns. In the example embodiment, this clustering is accomplished by a self-organizing map.

The self-organizing algorithm begins with a distance determination among all of the feature vectors in the

15 training set. A map is then formed with a number of discrete units. Associated with each unit is a weight vector, initially consisting of random values. Each of the feature vectors is inputted into the self-organizing map as a training vector. Units respond to the input

20 vector according to the correlation between the input vector and the unit's weight vector. The unit with the highest response to the input is allowed to learn by changing its weight vector in accordance with the input, as are some other units in the neighborhood of the

responding unit. The neighborhood can decrease in size during the training period.

The result of the training is that a pattern of organization emerges among the units. Different units

5   learn to respond to different vectors in the input set, and units closer together will tend to respond to input vectors that resemble each other. When the training is finished, the set of feature vectors is applied to the map once more, marking for each class the unit that responds

10   the strongest (*i.e.*, is most similar) to that input vector. Thus, each class becomes associated with a particular unit on the map, creating natural clusters.

These natural clusters can be further grouped by combining map units that represent similar output classes.

15   In the example embodiment, this clustering is accomplished by a genetic clustering algorithm. Once the self-organizing map clustering is established, it can be altered slightly by combining or separating map units. For each clustering state, a fitness metric is calculated

20   to determine the utility of the clustering. This allows the system to select which clustering state is optimal for the selected application. In the example embodiment, the fitness metric is a function of the within groups variance of the clusters. One example includes the Fisher

Discriminant Ratio, but similar metrics are well known in the art.

Once the output classes are established and the feature vectors are grouped into classes, a feature analysis portion 110 determines a minimum feature set for the classification analysis. In the example embodiment, this is accomplished through a principle component analysis. The principle component analysis provides a determination of how much of the variance between classes can be accounted for by each feature. A minimum feature set will include those features necessary to account for a predetermined level of variance.

After a minimum feature set is established, a system control program 112 begins an optimization process to determine the optimal classifier for the application. The system control program 112 selects a plurality of classifier models from a set of available models. In the example embodiment, available models include support vector machines, radial basis function networks, auto-associative networks, and self-organizing maps. Each classifier model is then subjected to an optimization process to select an optimal architecture for that model. Thus, an iterative loop 113 including an architecture determination portion 114, a parameter optimizer 118, and

a feature optimizer 120 will produce an optimal classifier
configuration for each selected classifier model.
Accordingly, while the description of these components may
speak in terms of optimizing a single classifier, the

5   iterative process takes place multiple times to optimize a
classifier corresponding to each classifier model. In the
example embodiment, this is a serial process, with the
classifiers being optimized in a sequence determined by
the system control program 112.

10   The optimization process begins at an architecture
determination portion 114. The architecture determination
portion 114 determines a classifier architecture for each
classifier model according to an optimization algorithm.
The architecture determination portion 114 generates new

15   classifier architectures by altering the structure and
mechanics of existing classifier architectures. For the
first trip through the optimization loop 113, a default
classification architecture is used.

        In the example embodiment, the optimization algorithm

20   is a genetic algorithm. Thus, a predetermined number of
default architectures are provided for evaluation within
each model. As a general rule, at least one of the
default classifier architectures for each model will
define a maximum degree of complexity. The optimization

loop 113 is conducted once for each of these
architectures, ten in the example embodiment, and the
generated classifiers are stored in a working memory 116.

Once the predetermined number of classifiers are

5   stored, the architecture determination portion 114 will
generate new classifier architectures based upon the
architectures in the working memory 116. In the example
embodiment, this is accomplished according to several
genetic algorithm strategies. One is crossover, where

10   features of one architecture are merged with those of a
second architecture. For example, the structure of the
hidden layers in a neural network classifier might remain
the same, but some of the connections between the hidden
layers can be changed to match a second classifier within

15   the working memory. Another genetic algorithm strategy is
mutation. Here, a random change is introduced to the
structure of an individual classifier architecture. For
example, in a neural network classifier, the number of
nodes in a hidden layer can be expanded by a random

20   number. These genetic algorithm strategies can be
modified according to a set of heuristic rules, depending
on the application. For example, where a series of
classifiers having similar architectures are unpromising
(i.e. having a classification accuracy below a threshold

value), more radical changes can be made to the
architecture, effectively ending the unpromising series.
The heuristics serve to eliminate some of the randomness
in the genetic algorithm and thus streamline the process.

5   The classifier architecture is initialized with
initial values appropriate to its structure and passed to
a parameter optimizer 118. At the parameter optimizer,
the parameters of the classifier represented by the
determined architecture are optimized to classify a set of
10   sample images. The means of this optimization will vary
with the classifier model.

The classifier architecture is then provided to a
feature optimizer 120. Using the minimum feature set from
the feature analyzer 110 as a starting point, the feature
15   optimizer determines an optimal set of features for the
classifier represented by the determined architecture. In
the example embodiment, a genetic algorithm is used for
this optimization as well. As with the overall
classification loop, the process will begin with a
20   predetermined number of example feature sets. These sets
will be altered by crossover, mutation or other strategies
until a termination event occurs. At this point, the
feature set optimizing a cost function will be selected.
In the example embodiment, the cost function will be a

function of the accuracy of the classifier, measured as
the number of misclassified and unclassified test samples,
and the processing time necessary to incorporate the
feature set.

5   After the feature set is optimized, the generated
architecture is evaluated at the system control program
112. The system control program 112 calculates a fitness
value for the classifier represented by the generated
architecture based upon its performance and efficiency in
10 classifying a test set of samples and calculating the
generated error. The system control program 112 then
compares this calculated fitness value to the fitness
values of the architectures stored in the working memory
116. If the new classifier architecture is more fit (i.e.
15 has a fitness value indicating superior efficiency, less
error and more accuracy) than the least fit of the
existing architectures, it replaces that least fit
architecture in the working memory 116. In the example
embodiment, the fitness function is a linear combination
20 of variables representing the size of the classifier, the
number of test samples that were not classified, the
calculated error and the number of test samples that were
misclassified. The coefficients modifying each of these

variables will change according to the application and the
specific classifier model being optimized.

The system control program 112 then determines if a
termination event has occurred. In the example
5   embodiment, the iterative optimization is terminated when
the fitness function meets a threshold value or after a
predetermined period of time. If no termination event has
occurred, the process continues to a new iteration. Upon
occurrence of a termination event, the program retains the
10 classifier represented by the architecture with the lowest
associated value of the fitness function. This classifier
is saved to memory as a representative classifier for its
associated classifier model.

The system control software 112 calculates a fitness
15 function for the representative classifiers for each
model. This fitness function is a function of the
complexity of the classifier architecture and the accuracy
and completeness of the classification of the test set
during optimization. A confusion matrix, or a grid of the
20 classification rates for each output category, is also
generated to better determine the classification
properties of the classifier at each output class. The
representative classifier having the best overall value

for this fitness function is selected as the optimal classifier and implemented.

Fig. 5 is a functional diagram of an example embodiment of the learning portion of the self-optimizing

5   classifier of the present invention implemented as computer software within a data processing system.   As with the previous diagram, the input patterns are images of envelopes and the objects to be classified are postal indicia.

10   The classifier 150 receives input images at a region of interest extractor 152.   The extracted images are sent to a feature extractor 154, where a feature vector is extracted containing the features selected for the classifier in the training portion 100.   The extracted

15   feature vector is sent to the classification portion 156, which implements the optimized classifier developed in the training portion 100.

The classification portion 156 attempts to match the input feature vector to one of a plurality of represented

20   output classes using the selected classification technique.   In this process, a class will be selected, and a corresponding confidence measurement will be calculated. If the confidence measurement is above a predetermined threshold, the feature vector is classified as the

corresponding class. If the confidence measurement does not exceed the threshold, the feature vectors are stored in a memory 158 for later analysis.

Once a sufficient number of image samples have been
5   accumulated, the image samples are passed to a clustering portion 160. The clustering portion 160 groups the image samples into clusters based upon similarities in their features. More precisely, the clustering portion 160 groups together those images whose feature vectors are
10   relatively close to one another within an N-dimensional space, where each of the N dimensions represents a feature variable. In the example embodiment, the clustering is performed by a self-organizing map, which operates similarly to the self-organizing map described for the
15   training portion 100.

The new clusters are sent to a controller program 162, which determines if any of the new clusters could represent a new output class. If a large number of pattern samples are gathered within a relatively small
20   cluster, the cluster likely represents a class. The exact density necessary to represent a class will be determined by experimentation with a particular application.

If any clusters are sufficiently dense to represent a new class, the clusters are passed to an artificially

intelligent trained program, referred to hereinafter as a

BOT 164. The BOT 164 checks the characteristics of the

clusters against at least one database containing

information about possible output classes. In the example

5   embodiment of a postal indicia recognition system, the BOT

164 searches one or more databases 166 maintained

internally by the classification system, references an

external database (not shown), connected via an Ethernet

connection and maintained externally, and searches an

10   Internet website to obtain new stamp images.

In the example embodiment, cluster characteristics

are calculated by averaging the feature vectors

representing the points forming a cluster across the

elements of the feature vectors to form a vector

15   representative of the cluster, a cluster mean vector.

Each cluster mean vector is compared to vectors derived

from the information provided by the databases. These

vectors may already exist in the databases, or they can be

derived from a sample from the databases by a feature

20   extraction process similar to that described above. These

vectors serve as representatives of classes within the

databases. Alternatively, feature vectors representing

classes from databases can be entered into the self-

organizing map of the clustering portion 160 to be matched
with particular clusters.

The controller program 162 determines if any of the
representative vectors within the databases match the

5   calculated cluster mean vectors. In the example
embodiment, a distance is calculated between the cluster
mean vector and each of the representative vectors in the
database. The distance calculation can be modified by the
number of elements in the vectors or the number of vectors

10 in the cluster in accordance with known statistical
theory. The smallest computed distance is then compared
with a threshold value. If the distance falls under the
threshold value, then the cluster can be matched with the
class represented by this closest vector.

15 When a match is found, the controller program 162
associates the pattern with the new class and directs the
BOT 164 to record the class information in the internal
database. The pattern samples forming the cluster are
saved to a memory 168 to be used in later retraining and

20 optimization of the classifier model by the training
portion 100.

If no match is found in the databases, the clusters
are sent to an expert verifier 170 to determine if the
clustered pattern samples are indicative of a new class.

In the example embodiment, the expert verifier 170 is a human operator. The expert verifier 170 identifies the clusters and directs the BOT 164 to input the results to the internal database 166. If a cluster is determined to

5 be a class, the pattern samples forming the cluster are saved to the memory 168 to be used in retraining and optimization of the classifier model by the training portion 100.

It will be understood that the above description of

10 the present invention is susceptible to various modifications, changes and adaptations, and the same are intended to be comprehended within the meaning and range of equivalents of the appended claims. The presently disclosed embodiments are considered in all respects to be

15 illustrative, and not restrictive. The scope of the invention is indicated by the appended claims, rather than the foregoing description, and all changes that come within the meaning and range of equivalence thereof are intended to be embraced therein.